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General Report — Session 8: Projects of Washington, District of Columbia, Maryland and Virginia Forensic Geotechnical Engineering Health Monitoring and Retrofit of Infrastructure

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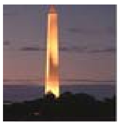

6th International Conference on
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PROJECTS OF WASHINGTON, DISTRICT OF COLUMBIA, MARYLAND AND VIRGINIA

FORENSIC GEOTECHNICAL ENGINEERING

HEALTH MONITORING AND RETROFIT OF INFRASTRUCTURE

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General Report – Session 8

INTRODUCTION

This General Report is presented in three sections. In the first section a summary of the topics covered by the papers presented in this session:

(a) Session 8a

Case Histories of Projects of Washington, District of Columbia, Maryland and Virginia; DC Monuments; Washington Monument, WWII Memorial, Lincoln Memorial, and Reflecting Pool; DC Convention Center, New I-95 Woodrow Bridge over the Potomac D.C. Metro, Springfield Interchange, The Dulles Light Rail Project

(b) Session 8b

Case Histories of Forensic Geotechnical Engineering, Where Things Went Wrong; Reliability of Codes; Risk Analysis Pertaining to Public Structures, Non-Destructive Evaluation and Load Testing of Drilled Shafts, Auger Cast Piles and Driven Piles; and Damage Evaluation and Advance Information, Systems in the Geotechnical Risk Predication and Assessment

(c) Session 8c

Case Histories of Health Monitoring and Retrofit of Infrastructure, including Bridges, Tunnels, and other Transportation and Geotechnical Structures

In the second section a summary of each paper is presented followed by general comments. Finally, the third section presents some remarks and topics for discussion.

SUMMARY OF RELATED TOPICS

Summary of Session 8a

This sub-session includes eight papers from projects founded in the soils of the District of Columbia, Maryland and Virginia. These projects are:

Washington, DC

Monuments on the National Mall (Paper 8.05a)
New I-95 Woodrow Wilson Bridge (Paper 8.07a)
11-Story Historic Building (Paper 8.01a)
Widening of Washington Beltway (Paper 8.04a)
Newseum Development (Paper 8.09a)
300 New Jersey Avenue Project (Paper 8.10a)

Virginia

Wastewater Treatment Plant Expansion (Paper 8.02a)

Maryland

New National Institute of Health Utility Tunnel (Paper 8.03a)

The topics addressed present foundation solutions that cover a great variety of problems in the area. Innovative modifications in the state of practice were employed to accommodate unique geologic conditions and subsurface setting of the DC metropolitan region.

The foundation problems can be grouped as follows:

Foundations

Deep - Piles (Papers 8.05a, 8.07a)
Shallow - Footings (Papers 8.02a, 8.05)

Support of Excavation

Sheeting/Shoring (Papers 8.01a, 8.03a, 8.09a, 8.10a)
Deep Piles and Footings (Papers 8.05a, 8.07a)

Embankments and Slope Stability

Mechanically Stabilized Earth (Papers 8.02a, 8.04a)

Soil-Structure Interaction

Piles (Paper 8.07a)
Walls (Paper 8.04a)

Monitoring & Testing

Support of Excavation, Underpinning (Papers 8.01a, 8.03a, 8.09a, 8.10a)
Surcharging (Paper 8.02a)
Mechanically Stabilized Earth (Paper 8.04a)
Pile Foundations (Paper 8.07a)

Sustainable Design

Resources of Borrow Material (Paper 8.02a)

<u>Summary of Session 8b</u>

This sub-session includes five papers from worldwide forensic case studies where things went wrong and one paper relating to risk analysis for a public structure. The projects presented cover a wide geographic range:

Africa

Buildings in Port Harcourt and southern region of Niger Delta, Nigeria (Paper 8.01b)
Road pavement, Ethiopia (Paper 8.05b)
Sports Complex, Botswana (Paper 8.05b)

China

Pipe Pile Foundations, JiaoMen Canal (Paper 8.06b)

Former Soviet Union

Ammonia storage tank in Ionava, Lithuania (Paper 8.03b)
9-story building in Sukhumi, Abkhazia (Paper 8.03b)

India

Mechanically Stabilized Earth Highway Bridge Approaches near Calcutta, India (Paper 8.04b)

USA

Flood Protection Levee System in Kansas (Paper 8.02b)

Although the papers examine significantly different failure types of structures ranging from buildings to roads, pavements, pile foundations, tanks, bridge approaches, and even levees, they all conclude that lack or poor subsurface investigation, standards lowering aimed at cost-reduction, and inappropriate construction methods are major factors that lead to these foundation failures. For the five case studies, the primary causes were:

Poor Evaluation of Subsurface Conditions

– Failure of 5-story building across a river channel in Nigeria attributed to reduction of strength parameters due to excessive pore pressure built-up in the foundations' sands and gravels when the ground water levels became higher during the rainy season (Paper 8.01b).
– Bearing capacity failure caused collapse of a two-storey building and death of construction workers in Nigeria. The developer built the house himself, without consulting with a geotechnical engineer (Paper 8.01b).
– Inadequate assessment of subsurface conditions led to global stability failure of the MSE walls used for two approaches of a highway bridge near Calcutta, India (Paper 8.05b).
– A pipe pile foundation failed during construction of a pumping station in southern China mainly due to vibration disturbance of a thick soft layer of very loose sludge and high water content. While the pile tips were resting on a lower sand layer, the vibration made the sludge layer behave like a liquid, flowing gradually during the excavation, applying an unbalanced lateral force on the piles that lead to failure (Paper 8.13b).

Inadequate Design

– The design of a failed road pavement in Ethiopia did not account for the expansive characteristics of the subsurface soils. In addition, inappropriate materials were used for construction and no soil improvement was considered. The fill materials in the road shoulders consisted of volcanic ash and tuffaceous material, replaced by silty clay in some sections, while drainage control was also inadequate (Paper 8.06b).
– The failure of a sports complex in Botswana was attributed, based on post-failure tests, to the fill material that did not comply with the project's requirements and to inappropriate remediation measures (Paper 8.08b).

Construction Methods & Specifications

– A building in Nigeria collapsed due to bearing capacity failure. The accelerated construction schedule did not allow dissipation of the pore pressures in the clay and consolidation of the foundation material (Paper 8.01b).
– Another building in Nigeria collapsed due to use of substandard concrete and steel materials (Paper 8.01b).

– Bearing capacity failure caused collapse of a two-story building and death of construction workers in Nigeria. The developer built the house by himself, without consulting with a geotechnical engineer (Paper 8.01b).

– The authority responsible for two structures in the former Soviet Union reduced the design specifications to achieve cost savings. As post-failure investigations showed, both structures failed due to the lowering of the standards: an ammonia storage tank in Lithuania exploded and a 9-story residential building in Abkhazia founded on a raft footing on largely spaced piles collapsed (Paper 8.04b).

In addition to the failure case studies, an application of risk analysis for a public structure is presented in Paper No. 8-02b for existing levees used for local flood protection of Topeka, Kansas. Conditional-probability-of-failure versus floodwater-elevation charts were derived to evaluate underseepage piping stability and slope stability for the long-term seepage. Several properties of the foundation and embankment materials were considered as random variables. The results combined with hydraulic analyses determined the economical risk of the levee existing conditions.

Summary of Session 8c

This sub-session includes eight papers on case histories of health monitoring and retrofit of infrastructure, including bridges, tunnels, and other transportation and geotechnical structures. The types of projects presented can be classified in:

Bridges & Viaducts

Evaluation of Geotechnical Characteristics for a Proposed Bridge in Lower Niger Delta, Nigeria (Paper 8.01c)

Investigations for a Road and Bridge in Nigeria (Paper 8.02c)

Bridge foundation retrofit using hollow core bar micropiles in New Jersey, USA (Paper 8.05c).

Investigation and monitoring of a landslide affecting a viaduct in Venezuela (Paper No. 8.08c)

Subways & Railways

Design and construction of an elliptical excavation for Porto Light Rail Metro in Portugal (Paper 8.04C)

Greek Railroad Network: Damage of Sleepers (Paper 8.09c)

Rehabilitation of Greek Railway Organization Railway line Korinth–Tripolis–Kalamata (Paper 8.13c)

Retaining Walls

Several retaining wall case histories are used to derive design parameters for the implementation of the Observation Method under the framework of Eurocode (Paper 8.12c)

PAPERS REVIEW

The papers are summarized and their conclusions discussed in this section. A summary of all paper is provided in Table 1.

Paper 8.01.a

“Case History of the Temporary Support of an 11-Story Historic Building in Downtown Washington, DC”

by D. Rothenberg and M. Hosseini (USA)

A unique two-tiered underpinning support system was created by Clark Foundations to support an 11- story historic building. The system consists of a system of bracket piles, a transfer girder and flat jacks. A new office building adjacent to the historic building required subgrade to extend approximately 10 feet below the tip elevation of those original bracket pile system that was built in the 1960’s. The excavation for the new building will be 65 feet deep. The Clark Foundation underpinning system was designed to support the 1960’s system that ultimately supports the historic structure.

The extensive preliminary site investigations and timely collaboration with the structural engineer, proved invaluable in providing a safe and adequate underpinning design solution. The solution provided additional below-grade space while maintaining the integrity of the historic structure. The underpinning system performed exceptionally well, as monitoring and surveying showed that: (i) the deflections were limited by the use of flat jacks that preloaded the system; and (ii) the brackets and soldier beams encased in concrete showed little or no signs of corrosion, from more than four decades of exposure to groundwater. This enhances the practical view of concrete backfill providing adequate protection against corrosion for steel brackets.

Fig. 13, Paper 8.01.a: Site excavation completed looking west at supported wall (©D. Cunningham).

Table 1. Submitted Papers to this Session.

Session 8a: Projects of Washington, District of Columbia, Maryland and Virginia

Paper Authors	Title of Paper	Field of Application	Summary of Content	Approach	Location
#8.01.a Rothenberg, D. Hosseini, M.	Case History of the Temporary Support of an 11-Story Historic Building in Downtown Washington, DC	Support of Excavation	A unique two- tiered underpinning support system supports an 11-story historic building, providing additional below-grade space while maintaining the integrity of the historic structure.	Underpinning System, Monitoring	Washington, DC (USA)
#8.02. a Shah, H.J. Lacy, H.S. Van Rensler, M.B.	Mechanically Reinforced Earth for Steep Surcharge Slopes in Proximity of Adjacent Structures to Improve Compressible Soils	Embankments and Slopes, Shallow foundations	Surcharge embankments of mechanically stabilized earth addresses complex slope geometrics, subsurface conditions and nearby critical utilities and structures.	Mechanically Stabilized Earth (MSE), Surcharging, Monitoring	Virginia (USA)
#8.03.a Surber, C. Hosseini, M.	Excavation and Shoring Support for the National Institutes of Health East Redundancy Loop Project at Building 10 on NIH Campus in Bethesda, Maryland	Support of Excavation	Solutions for the support of excavation and shoring system beneath an existing NIH tunnel resulted in accelerated project schedule, minimization of cost and maintenance of daily pedestrian traffic.	Soldier and bracket piles, walers, Monitoring	Maryland (USA)
#8.04.a Klein, E.M. Trinble, J.L. Shrestha, B.B.	Tied-Back Top-Down Wall to Support I-295 Ramp	Embankments and Slopes	Widening I-95 from 3 to 6 lanes required supporting existing ramps and a 17-ft tall, 570-ft long Mechanically Stabilized Earth (MSE) wall. Predicting wall deformations is addressed.	FEM analysis, MSE analysis, Monitoring	Washington, DC (USA)
#8.05.a Christie, D.W.	Foundations for Memorials and Monuments on the National Mall	Shallow and Deep Foundations	Overview of the geology of Washington, DC. Description of types and performance of foundations of several National Mall monuments.	Site Characteristics, Historic Records, Geology	Washington, DC (USA)
#8.07.a Ellman Jr., R.A.	New I-95 Woodrow Wilson Bridge Foundations	Deep Foundations	Design and performance of deep foundations used to support the new Woodrow Wilson Bridge.	Numerical Analyses, Design Phase Testing	Washington, DC (USA)
#8.09.a Omelchenko, V. Hosseini, M.	Excavation Support for Newseum Development at 555 Pennsylvania Ave. in Washington, DC	Support of Excavation	Application of a Pile in Self Hardening Grout (PSHG), successfully used as temporary excavation support system.	PSHG system, H-piles, Secant Pile Wall, Monitoring	Washington, DC (USA)

Table 1. Submitted Papers to this Session (cont'd).

Session 8b: Forensic Geotechnical Engineering

Paper Authors	Title of Paper	Field of Application	Summary of Content	Approach	Location
#8.01.b Teme, So-Ngo C. Ngerebara, O.D. Ubong, E.	Need for Prior Geotechnical Engineering Studies for Foundation Design: Cases of Collapsed Buildings in Port Harcourt and Environs, Nigeria	Subsurface Conditions	Collapse of major buildings in southern region of Niger Delta. Failure mechanisms due to poor or no subsurface data were punching, bearing capacity and overturning failures.	Post-failure testing	Niger Delta (Nigeria)
#8.02. b Perlea, M. Loehr, S.	Geotechnical Risk Analysis of the Local Flood Control Projects on the Kansas River in Topeka, Kansas	Risk Analysis	Geotechnical risk and uncertainty analysis with hydraulic analyses used to analyze performance of flood protection of Topeka, Kansas.	Analysis	Topeka, Kansas (USA)
#8.04.b Arshba, E.T. Barvashov, V.A. Vasyukov, G.V.	Two History Cases of Innovations	Specifications Construction methods	Failures linked to some cost saving procedures accepted by the former Soviet Government, lowering technical requirements for safe design and construction.	Specifications	Ionava, (Lithuania) Sukhumi, (Abkhazia)
#8.06.b Roy, D. Singh, R.	Failure of Two High Embankments at Soft Soil Site	Inadequate Design	Failures of Mechanically Stabilized Earth (MSE) embankments due to inadequate design and lack of subsurface information caused global stability failure.	Post-failure testing	Calcutta (India)
#8.08.b Mgangira, M.B. Paige-Green, P.	Damage to a Road and Sports Complex on Expansive Clays	Inadequate Design	Damage to road pavement in Ethiopia, and sports complex in Botswana due inadequate evaluation of the soil characteristics.	Post-failure testing	Ethiopia Botswana (South Africa)
#8.13.b Yu, X (Bill) Huang, Y	Forensic on Construction Induced Failure of Pipe Pile Foundations	Subsurface Conditions	A pipe pile foundation failed during construction of pumping station due to vibration disturbance of a thick soft layer that behaved like a liquid and applied unbalanced lateral force on the piles that lead to failure.	Post-failure testing	JioaMen Canal (China)

Table 1. Submitted Papers to this Session (cont'd).

Session 8c: Case Histories of Health Monitoring and Retrofit of Infrastructure, including Bridges, Tunnels, and other Transportation and Geotechnical Structures

Paper Authors	Title of Paper	Field of Application	Summary of Content	Approach	Location
#8.01.c Teme, So-Ngo C. Ubong, E.	An Evaluation of the Geotechnical Characteristics of a Proposed Bridge across a 400-m River Channel in the Lower Niger Delta, Nigeria	Design Soil Properties	Provides information on the geotechnical characteristics of the foundation soils of a 400-m long bridge across the Niger Delta.	Subsurface Investigation, Laboratory Testing	Niger Delta (Nigeria)
#8.02.c Teme, So-Ngo C. Ubong, E.	Subsurface Investigations for 9.8-km long Road/130-m wide Bridge in Karst Topography, South Nigeria	Design Soil Properties	Foundation conditions, design analyses of a bridge crossing the Kwa River located in the south-eastern section of the Niger Delta sub-region of Nigeria.	Subsurface Investigation, Laboratory Testing	Niger Delta, (Nigeria)
#8.04.c Gomes, A.T. Cardoso, A.S. eSousa, J.A., Andrade, J.C., Campanhã, C.A.	Design and Behaviour of Salgueiros Station for Porto Metro	Deep Excavation	Presents design and construction of an elliptical 22-m deep excavation using the Sequential Excavation Method.	Numerical Modelling, Monitoring	Salgueiros Station (Portugal)
#8.05.c Gómez, J.E. Rodriguez, C.J. Robinson, H.D. Mikitka, J. Keough, L.	Bond Strength of Hollow-Core Bar Micropiles	Bridge Foundations Retrofit	Discusses foundation retrofit of two bridges using hollow-core bar micropiles, one submerged in granular soil and the other in predominantly fine soil.	Design and installation Approach, Quality Control	New Jersey (USA)
#8.08.c Fargier-Gabaldon, L.B. Salcedo, D.A. Camargo-Mora, R.	Ancient Landslide Reactivation at Viaduct No. 1 Located on Caraca-La Guaira Highway	Landslides Effects on Viaducts	Reactivation of an ancient landslide affected a viaduct of a highway in Caracas. Details on analyses, damage, field observation and rehabilitation measures.	Understanding of Failure Mechanism, Monitoring, Back Analyses	Caraca-La Guaira Highway (Venezuela)
#8.09.c Giannakos, K.	Damage of Railway Sleepers under Dynamic Loads: Case History from Greek Railway Network	Railway Response to Dynamic Loading	Cracks presented on 60% of the twin-block concrete ties laid on a track with maximum operational speed of 140 km/h are analysed.	Bibliographical search, Numerical analyses	(Greece)
#8.12.c Yeow, H-C. Feltham, I.	Case Histories Back Analyses for the Application of the Observational Method under Eurocodes for the SCOUT Project	Retaining Walls	Development of methodology to derive design parameters for the Observation Method of Eurocode for retaining walls. Describes project background, design optimizations and back analyses undertaken.	Observation, Method of Eurocode, Instrumentation, Back analyses	(United Kingdom)
#8.13.c Tsoukantas, S. Tzanakakis, D. Spyropoulou, D. Panopoulos, P	Investigation on Causes of Longitudinal Cracks on Prestressed Monoblock Railway Sleepers of Metric Gauge of the Greek Railway Network	Railway Rehabilitation	Observations and analyses of longitudinal cracks in some prestressed monoblock sleepers of metric gauge during rehabilitation of part of the Greek Railway Organization (OSE).	Site Investigation, Analytical considerations, Materials	Korinth, Tripolis & Kalamata (Greece)

Paper 8.02.a

"Mechanically Reinforced Earth for Steep Surcharge Slopes in Proximity of Adjacent Structures to Improve Compressible Soils"

by H.J. Shah, H.S. Lacy, and M.B. Van Rensler (USA)

Shallow foundations following surcharge to pre-consolidate the compressible soils at a site in Virginia was chosen to support a large expansion of an existing wastewater treatment plant. Tall and steep surcharge embankments were constructed of mechanically stabilized earth (MSE) addressing complex slope geometries, subsurface conditions and nearby critical utilities and structures. Potential sources adjacent to the site were investigated for procurement of the large volume (> 1 million cubic yards) of borrow material required for the surcharge. Monitoring was performed during construction to ensure the surcharging program performed as designed. Some of the conclusions drawn from this challenging project:

- Employing surcharging in this developed site required careful consideration of the impact to existing facilities, performance of detailed geotechnical investigations, constructability issues and monitoring.
- Detailed site characterization helped to identify soil stratigraphy and parameters for design of the various MSE slopes.
- Detailed off-site investigation revealed sources of borrow material in adjacent farms that proved cost-saving and reduced traffic, dust and noise. Returning the borrow soils to the farms after use demonstrated sustainability of resources.
- Close proximity of the existing structures and the future facilities dictated the need for providing tall (up to 39 feet tall) and steep (up to 1H:4V) surcharge embankments.
- Design of the MSE resulted in ratio of reinforcement embedment length to MSE slope height of 2.8, higher than what would be required for stable foundation soils (generally less than 1).
- The inter-layering of sand within the soft clay provided additional strength to enable stability of the surcharge slopes and reduced the time for surcharging by reducing drainage paths.
- The high strength / low strain properties of the Huesker Comtrac® woven polyester geotextiles used for the MSE demonstrated that geotextiles is an economic alternative to geogrids for such applications.
- Monitoring performed during the surcharging program demonstrated:
  - Movement at the existing structures (< 0.5 in) and utilities (< 2 in) in proximity to the surcharge areas and settlements of embankments (< 16 in) were all within estimated values.
  - Lateral movements (< 2 in) at the MSE slope toes showed global stability during surcharging.
  - Pore pressures at embankments base due to tolerable rate of surcharge placement and the inter-layered character of the subsurface clays, silts and sands.

Fig. 7, Paper 8.02.a: Wrapped face of acid digester steep surcharge slope under construction.

Paper 8.03.a

"Excavation and Shoring Support for the National Institutes of Health East Redundancy Loop Project at Building 10 on NIH Campus in Bethesda, Maryland"

by C. Surber and M. Hosseini (USA)

The new National Institutes of Health (NIH) Utility Tunnel development will extends 28 feet below existing grade and 16 feet below the existing tunnel located on the NIH Campus in Bethesda, Maryland. The development consists of an underground concrete utility vault (about 44 ft long by 25 to 32 ft wide) and tunnel (about 30 ft long by 16 ft wide). The top 24 feet of soil consist primarily of fill, a mixture of silty sand and sandy silt with an underlying layer of disintegrated schist rock. The proposed tunnel/vault structure is supported by a 2.5 foot thick mat foundation.

The paper describes the solutions for the support of excavation and shoring system by Clark Foundations that would allow the installation of the proposed utility vault and connection tunnels beneath the existing NIH tunnel. A large scale utility hanging system was conjured, consisting of 9 soldier piles and 27 bracket piles, each drilled from existing grades prior to excavation. As the existing cast-in-place utility tunnel structure was uncovered, brackets were installed on the surrounding bracket piles while the surface was prepared to receive the proposed epoxy rods. The support system utilized drilled epoxy Williams' threaded bars to transfer loads into supporting double c-channel walers and strong-back cross members. Each strong-back was designed to compensate for the calculated deflection of the tunnel once the below-structure excavation operations began. Distribution walers and header beams were utilized along the length of the existing utility tunnel and connected at the surrounding bracket piles. Upon successfully jacking the epoxy rods, the tunnel loading was directly transferred into the underlying bracket piles and distributed into soils below the proposed structure. Beneath the structure, each bay between bracket piles was lagged while the opposite site was sloped to create a tunnel for the underpinning access. Excavation commenced to the proposed subgrade at the completion of the underpinning piers. The remaining utility vault portion was completed upon the installation of an external waler and internal strut bracing system, specifically designed to eliminate the need for excessive patching with the newly poured cast-in-place below-grade walls.

Monitoring strips and points were installed along the tops of each bracket pile and along the roof of the existing tunnel structure. Crack monitors were installed at an existing expansion joint located directly in the center of the supported tunnel system. At the overall completion of the project, there were no signs of settlement within existing utility tunnel as well as notable movement of solder and bracket piles. The unique shoring system conceived and utilized by Clark Foundations resulted in accelerated project schedule, minimization of the cost, and maintenance of the daily pedestrian traffic.

Photo 10, Paper 8.03.a: Completed support of excavation and shoring systems.

Paper 8.04.a

"Tied-Back Top-Down Wall to Support I-295 Ramp"

by E.M. Klein, J.L. Trimble, B.B. Shrestha (USA)

Woodrow Wilson Replacement Bridge Project included widening the Washington Beltway (I-95/I-495) Outer Loop from three to six lanes. This required supporting two existing ramps that connect I-295 and MD 210 as well as the existing Mechanically Stabilized Earth (MSE) wall that supports the ramps. The MSE is about 17-ft tall, about 570-ft long, and at the top of a slope. A tied-back soldier pile and lagging wall with cast-in-place facing was selected to support the MSE and the ramps. The new wall will be about 1,376-ft long and will be as high as 37-ft. The closest approach of the wall to the existing MSE is about 3 ft.

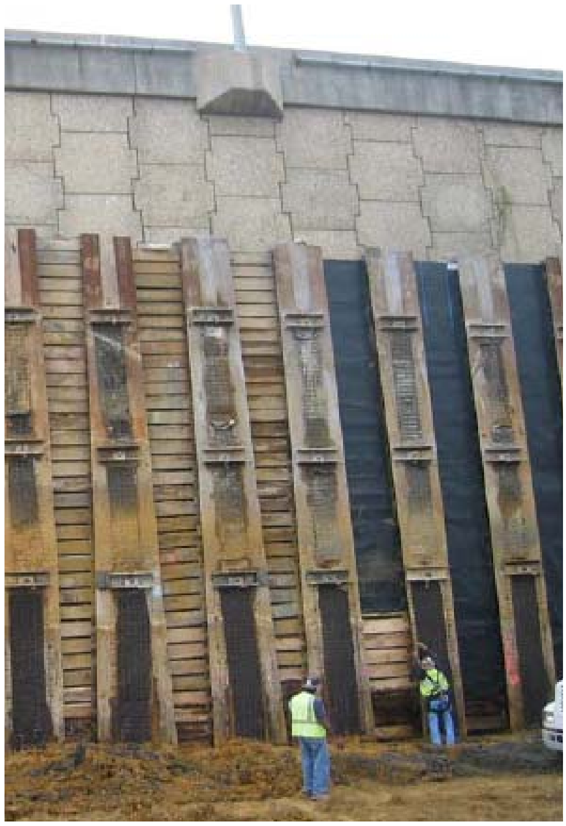

Fig. 3, Paper 8.04.a: Photograph of soldier piles showing the existing MSE.

The paper addresses the difficult task of predicting wall deflections and settlements in this project. Laboratory testing was supplemented with Dilatometer Test (DMT) and Cone Penetration Tests (CPT). The programs PYWall and PLAXIS were used to estimate wall deflections and bending moments in the soldier piles. The paper reviews the analysis techniques, describes the design and construction methods, and presents the instrumentation used to monitor the wall and MSE movements. Results of the computer simulations were compared to the inclinometer results. As work progressed simulations were updated by modifying the soil parameters to obtain calculated results that are more nearly consistent with the instrumentation readings. The following can be concluded:

- FEM and p-y techniques can be used to evaluate instrumentation locations; develop limiting criteria for instrumentation; compare alternatives during design;

evaluate effect of soil parameters variability; evaluate different construction techniques and sequence.

Fig. 11, Paper 8.04.a: Finished wall with MSE

- Back analysis techniques can be useful for recalibration during construction monitoring and to update and possibly revise the threshold and limiting values contained in an instrumentation plan.
- DMT can be used to provide more accurate deflection estimates but could be unconservative.
- Conventional laboratory test results used in modeling lead to satisfactory predictions of the observed behavior.
- Understanding local geology and using geotechnical testing is critical to derive variability of soil parameters.
- Compressive strength test results underestimated deflections as compared to triaxial extension tests that would be preferred as the latter mimics likely actual stress paths during construction.

Paper 8.05.a

"Foundations for Memorials and Monuments on the National Mall"

by D.W. Christie (USA)

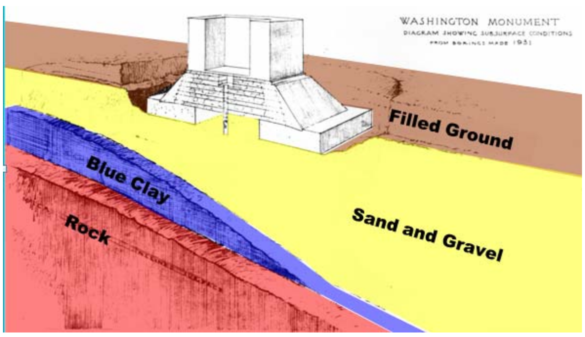

Fig. 7, Paper 8.05.a: Perspective view at the base of the Washington Monument (1931).

This paper presents an excellent overview of the geology of the Washington, DC area and a description of the types and performance of foundations of many well-known memorial and monument structures on the National Mall.

The selection of foundation type in Washington, DC is driven by subsurface conditions, building design, cost and schedule. As the western end of the National Mall in Washington, DC was made by filling in portions of the Potomac River, memorials and monuments have required deep foundations. The site history including stream channels, canals, and materials used in filling various areas has had a large impact on the development of the Mall.

Fig. 10, Paper 8.05.a: Reinforcing cage being placed for WWII Memorial slurry wall (2002).

Variations in geologic conditions along the Mall have affected the types of foundations used. In general, the major memorials and monuments on the western half of the Mall require deep foundations to rock, due to the poor quality of the soils in this area, most of which are dredge spoil placed in the late 1800's. Museum demands below grade call for deep foundations, often combined with slurry walls, to provide high quality space without intruding on sight lines. Off the Mall, deep foundations are generally dictated by the need to develop underground space for parking or building function while supporting the neighboring structures and streets.

One of the earliest structures, the Washington Monument, was sited to account for problem soils. Its foundation was underpinned during construction to compensate for low-strength soils. Shallow-founded portions of the Lincoln Memorial, the Reflecting Pool, and the Jefferson Memorial have experienced settlements requiring repair. Foundations for the Korean, Vietnam, and World War II Memorials were designed as deep systems due to the presence of compressible deposits at their respective sites and in the case of the World War II Memorial the presence of a flood zone. The US Capitol is founded at a higher elevation on spread footings bearing on compact Pleistocene terrace deposits.

Paper 8.07.a

"New I-95 Woodrow Wilson Bridge Foundations"

by R.A. Ellman, Jr. (USA)

This paper presents the design and performance of deep foundations used to support the new Woodrow Wilson Bridge (WWB). The types of deep foundations used for the project, performance criteria assumed during the design, measured performance and difficulties encountered during construction, and resulting remedial actions, i.e., changes to contract installation criteria and/or re-design due to the unanticipated field conditions are shown in detail.

Fig. 2, Paper 8.07.a: Computer generated photographs of the new Woodrow Wilson Bridge.

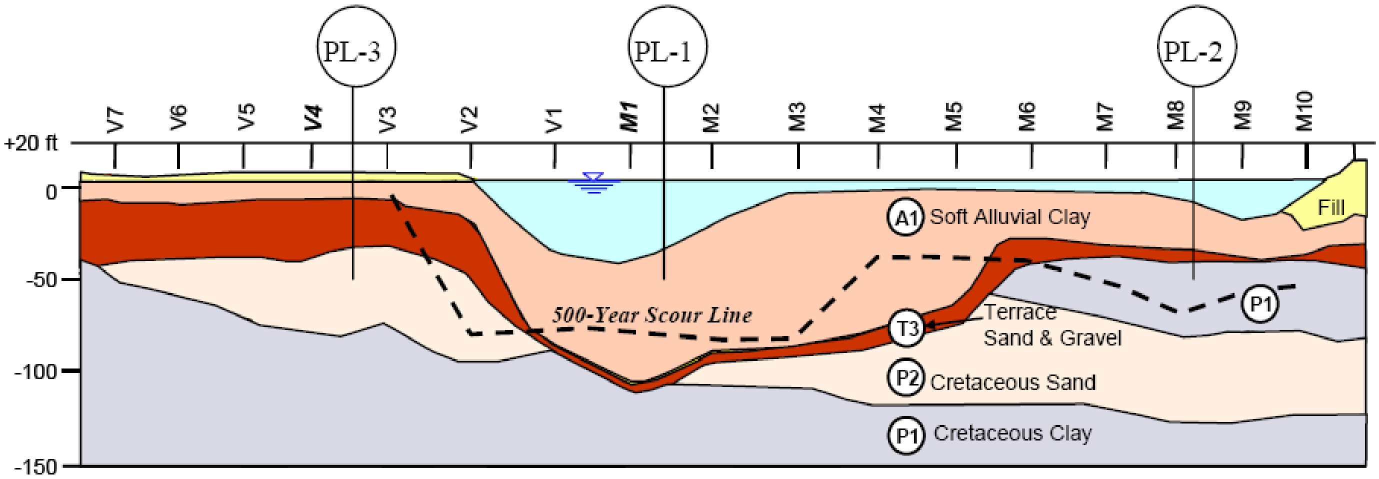

Fig. 3, Paper 8.07.a: Soil and estimated scour profile, bridge pier locations, and pile load test locations.

The new bridge will replace the existing bridge over the Potomac River to connect Alexandria, Virginia to Prince Georges County, Maryland. It will extend approximately 1.1 miles across the river, with a 367- ft long bascule span in the main river channel where the water depth is about 36 ft. The bridge is primarily comprised of fixed spans in relatively shallow water and a bascule span over the navigation channel. The subsurface soil profile was quite variable along the bridge alignment. In Virginia there was fill over soft alluvial deposits, underlain by dense Terrace deposits, as well as remnant foundations from a former ship yard. At the bascule span there was up to 50 ft of a soft organic silty clay layer underlain by a deep deposit of stiff Cretaceous clay. Along the Maryland approach there were Alluvial deposits over dense Terrace deposits over stiff Cretaceous clays and dense Cretaceous sands. The variation in subsurface conditions lead to the selection of alternative deep foundations that suited the specific conditions and were based on the design phase testing program, that determined ultimate design capacities.

During construction there were instances of unexpected pile performance, notably different than that experienced during the design phase testing, requiring changes to the contract installation criteria and redesign.

The experience from design phase testing and production pile installations lead to the conclusions:

- The ability to perform design phase testing enabled the designers to optimize the foundations for the new WWB, resulting in significant cost savings for the project.
- Simplified installation using specified tip elevation and elimination of static load tests during construction, in combination with dynamic testing facilitated quality assurance and control during construction and allowed for quick response and remedial action in the field.
- The ability to perform design phase testing enabled the designers to optimize the foundations for the new WWB, resulting in significant cost savings for the project.
- Simplified installation using specified tip elevation and elimination of static load tests during construction, in combination with dynamic testing facilitated quality assurance and control during construction and allowed for quick response and remedial action in the field.
- Specified Tip Criteria:
  - Can be successfully used where there is sufficient uniformity in the bearing stratum and performance of piles has been documented by a thorough design phase testing program.
  - May prove to be problematic where there is a non-uniform bearing stratum and response of piles within the stratum. For these conditions, an Estimated Tip approach may be more reasonable.

<u>**Paper 8.09.a**</u>

"Excavation Support for Newseum Development at 555 Pennsylvania Ave. in Washington, DC"

by V. Omelchenko and M. Hosseini (USA)

The Newseum is located on Pennsylvania Avenue, between the U.S. Capital and the White House next to the Washington, D.C. mall and its museums and monuments. The paper presents the application of a Pile in Self Hardening Grout (PSHG) that was successfully used as temporary excavation support system at the Newseum Development, as a value engineering substitution of a soil-mix wall system. The Newseum consists of a 650,000 sq-ft development that includes a six-level, 215,000 sq-ft interactive museum of news.

Also included is office space for the Newseum and Freedom Forum staff, a 9,000 sq-ft conference center, more than 30,000 sq-ft of retail space and about 100 condominiums. The building is supported on a mat foundation, located just north of the Old Tiber Creek that was filled in the early 1800's. Soft and compressible soils are present in the area, prone to settlement from dewatering. These soils have been associated in the past with large movements of conventional H-pile and wood lagging excavation support systems and other problems. Therefore, various "cut-off" walls were considered for excavation support that would not allow ground water around the building excavation to drop and be less prone to soil erosion through wood lagging boards. Cut-off walls considered were a slurry wall, soil-mix wall, secant pile wall and Pile-in-Self-Hardening-Grout (PSHG) wall.

Fig. 2, Paper 8.09.a: Existing foundation system with Raymond Step Taper piles.

The PSHG wall was selected for 3 sides of the excavation and constructed by inserting pre-fabricated panels of steel H-piles and wood lagging into pre-excavated trenches using clamshell equipment normally used for slurry wall construction. A low strength self-hardening grout was used within the excavations to keep the sidewalls from caving, which hardened to strength of about 60 to 70 psi within few days after installation of panels. The PSHG wall resulted in a relatively impermeable cutoff wall.

Fig. 5, Paper 8.09.a: Clamming operation for PSHG wall.

A secant pile wall system was utilized for the east face of the excavation adjacent to the existing Canadian Embassy due to concerns about ground loss beneath the Embassy. Ground water observation wells were monitored during construction to confirm that excessive ground water lowering below the Embassy mat did not occur. In addition, inclinometers and settlement points were monitored to measure movements of the Embassy, secant pile and PSHG walls. Both PSHG and secant pile walls were supported with tiebacks and both systems performed well within specified tolerances.

The PSHG wall and secant pile wall systems were able to reduce the quantity of groundwater inflow in the excavation and were rigid enough such that horizontal and vertical movements of the excavation support system and Embassy were within specified project criteria.

<u>Paper 8.10.a</u>

"Temporary Support of Excavation for 300 N. Jersey Ave"

by I. Ragsdale and K. Wadia (USA)

This paper discusses the unique and challenging design, construction, and performance of the support of excavation system used at a project located at 300 New Jersey Avenue in Washington DC selected for the variable site conditions. The system was designed to support a six and seven story office building, WMATA's Red Line Subway tunnel under D Street and the support of the 24 foot wide brick and stone Tiber Creek Sewer, which was built in the late 1800's to drain a major portion of the city. The depth of the excavation is 60 ft. The top 30 ft of soil is a mix of Miocene Age Terrace deposits of sand, gravel, silt, and clay, while the bottom 30 ft is hard Cretaceous clay. The groundwater at the interface at the top of the clay was a concern due to the possibility of washing away the upper soils during installation of typical soldier beams and wood lagging. Therefore, Clark Foundations chose to use slurry wall clamming techniques to install Piles in Self Hardening Grout (PSHG) on two sides of the site and tangent/bracket piles on the side adjacent to the existing buildings. The bracing included tiebacks, corner braces, wales, rakers, and cross lot struts. In addition Pin Piles with support steel were installed to hold the existing utilities under First Str. and a suspended platform for the excavator's long stick backhoe.

The sheeting and shoring system performed very well and limited the movement of the critical surrounding structures. The Acacia building and the soldier pile adjacent to the building moved less than 0.375 inch both vertically and horizontally and the WMATA tunnel moved less than 0.25 inch vertically and horizontally. The combination of the tangent wall, PSHG Wall and the 7 deep wells created a sufficient bath tub that kept the jobsite dry during the excavation process. The excavation team also performed very well in adapting to the difficult site conditions. When differing site conditions were encountered the team was able react to the situation and immediately come up with a solution to keep the excavation progressing without delays to the tight schedule. This was possible due to the cooperation and collaboration of the entire project team. Throughout the 9 month duration of the support of excavation work, more than 44,000 man hours were worked in very difficult conditions, without one lost time injury.

Fig. 5, Paper 8.10.a: PSHG wall clamming operation with service crane holding panel to be set.

Fig. 9, Paper 8.10.a: Tangent wall drilling operation.

<u>Paper 8.01.b</u>

"Need for Prior Geotechnical Engineering Studies for Foundation Design: Cases of Collapsed Buildings in Port Harcourt and Environs, Nigeria"

by So-Ngo C. Teme, O.D. Ngerebara, & E. Ubong (NIGERIA)

The authors analyzed the collapse of four major buildings in the Port Harcourt and in the southern region of Niger Delta, in Nigeria. The absence and/or inadequate the geotechnical investigation of the building's foundation conditions contributed substantially to the foundation failures of numerous buildings in the major cities in Nigeria. The discussed cases are the following: (1) the failure of a five story building constructed across a river channel due to reduction of the strength parameters due to excessive pore pressure built-up in the foundation's sands and gravel due to high ground water elevation during rainy season, (2) bearing capacity failure conducting to collapse of a building at the end of construction due to rapid construction that did not allowed dissipation of the pore pressure in the foundation clay and consolidation of the foundation material, (3) collapse of a building due to rapid construction that did not allowed the curing of the concrete - actually this is a structural failure and not a foundation failure, and (4) collapse of a residential building due to complete lack of foundation condition investigation. The authors described the failure mechanisms analyzed in these case histories as: (1) "punching failure" as the loss of the bearing capacity of the saturated sandy soils in the foundation by reduction of the effective strength of the sand with the increased pore pressure, if the sandy foundation material is covered by a layer of impervious soil that does not allow the dissipation of the pore pressure created by rapid rise of the groundwater during rainy seasons, (2) "bearing capacity failure" if the load on the foundation soil exceeds the soil's bearing capacity, (3) "overturning failures", similar with bearing capacity failure except the uneven distribution of stresses that lead to differential settlements actually, and (4) "structural failures." due to bad structural design or inadequate construction methods. The paper presented the results of the geotechnical investigation and analyses performed after the collapse of the building, including soil profiles at the location of the failure, analyses of the bearing capacity, and also provided pictures of the damaged buildings.

Fig. 6b, Paper 8.01.b: Remains of the collapsed building along the New Tombia Extension Road GRA III, Port Harcourt.

Paper 8.02.b

"Geotechnical Risk Analysis of the Local Flood Control Projects on the Kansas River in Topeka, Kansas"

by M. Perlea and S. Loehr (USA)

The paper presents results of geotechnical risk and uncertainty study of the existing conditions for the local flood protection of Topeka, the state capital of Kansas. The existing levee system constructed by the US Army Corps of Engineers consists of 6 levees units along the north and south bank of the Kansas River and tributaries, Soldier Creek and Shunganunga Creek.

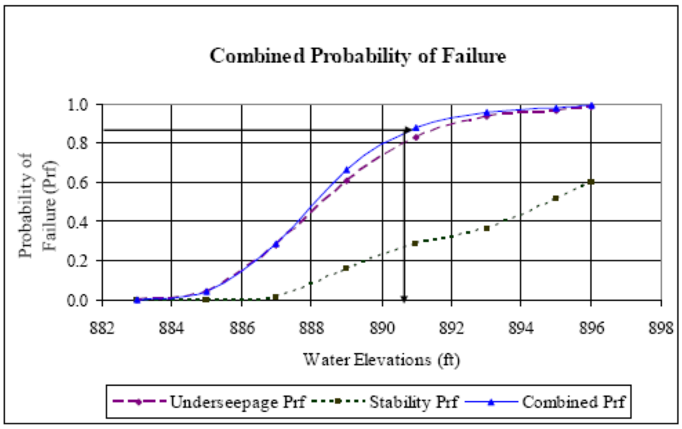

Fig. 10: North Topeka Unit - combined probability of failure.

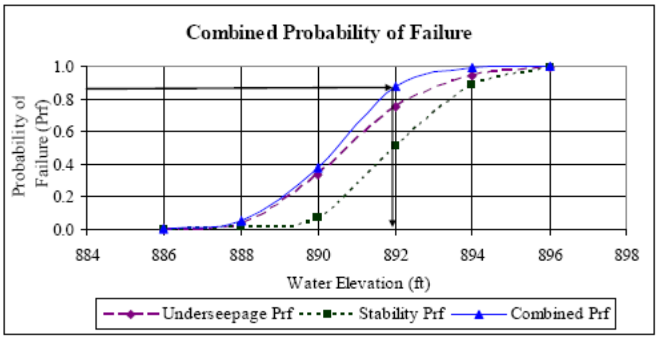

Fig. 11: Waterworks Unit - combined probability of failure.

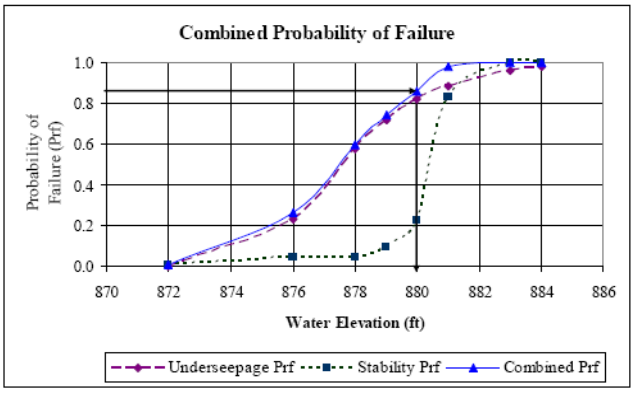

Fig. 13: Oakland Levee Unit - combined probability of failure. (all three figures from paper 8.02.b)

The geotechnical risk based evaluation of the existing conditions of the levee system was based on all available geotechnical data and on the past performance of the system. Critical reaches of each levee unit were identified based on the geotechnical conditions and levee geometry. The geotechnical levee system response to river stage loading for these critical reaches was evaluated. Geotechnical information included subsurface investigation performed for the design and construction of the levee, geotechnical information obtained for subsequent levee modification, and cone penetrometer tests and laboratory testing performed on selected samples collected from additional borings drilled in areas considered critical or known to experience excessive underseepage during previous flooding events. Uncertainty analyses were performed to define the existing condition of the Topeka Levee System.

The system response was determined by evaluating the foundation and embankment materials and assigning values for the probability moments of the random variables considered in the analyses. The performance functions considered for the risk analyses were slope and underseepage piping stability. Internal erosion due to seepage through the embankment was not considered, the levee embankments being constructed of cohesive fill.

A set of conditional-probability-of-failure versus floodwater-elevation graphs were developed as related to underseepage piping stability and slope stability for the long-term seepage. Reliability analysis was performed using Taylor's Series Method. In the Taylor method, random variables were quantified by their expected mean values, standard deviations, and correlation coefficients**.** The results of the geotechnical risk and uncertainty analysis together with risk based hydraulic analyses were then used for determination of the economical risk of the levee existing conditions.

Paper 8.04.b

"Two History Cases of Innovations"

by E.T. Arshba, V.A. Barvashov, and G.V. Vasyukov (RUSSIA)

The paper provides information on two failures linked to cost saving procedures accepted by the former Soviet Government disregarding the technical requirements for a safe design and construction. The described failures are an explosion of a liquid ammonia storage tank in Ionava, Lithuania and the collapse of a 9 stores residential building in Sukhumi, Abkhazia founded on a raft footing on largely spaced piles.

The explosion of the ammonia tank created a highly toxic environment after the tank was completely destroyed, with numerous fatalities at the facility site. The tank was founded above the ground on a two-slab concrete footing for thermal control, with concrete columns spanned at 1.5 m interval between the slabs. The tank was surrounded by a high safety wall. The foundation soil consisted of dry sand, with the water table 3290 m below the surface. During 11 years of operation the tank settled 11- 12 cm in the center and 6-7 cm at the edge The paper describes the innovative design that overestimated the bending moments in spread footing not taking in consideration the "plastic zones" under footing edges. Numerical modeling performed after the tank failure were in concordance with the field observations showing the edges of the upper slab "curled up" and broke due to the peripheral anchors and the excessive large load of the tank.

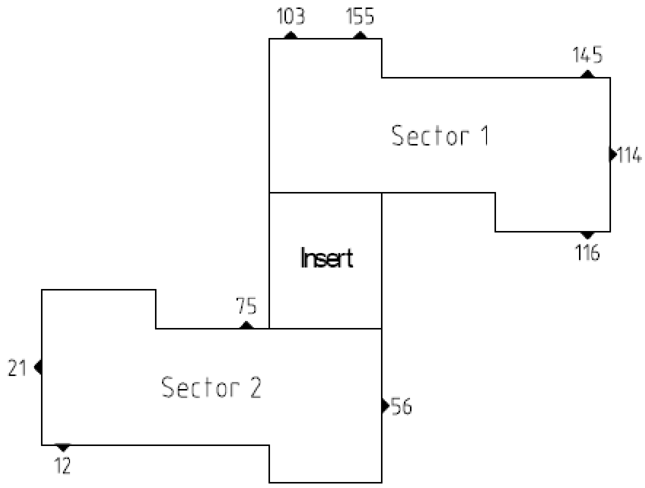

Fig. 2, Paper 8.04.b: The raft overview, showing measured settlements (mm).

The collapsed buildings consisting of two separate 9-stores buildings with an insert between them were founded on a 40 cm thick concrete slab supported by 12 m long 35x35 cm diameter piles spaced at 3x3 m interval instead of 1x1 m for constructability reasons. The quality of the concrete raft was also lower than required by design. After the construction was completed the piles punched through the raft at one or two locations. The foundation soils consisted of soft soil at the surface followed by a stiff layer of gravel; therefore the piles were point bearing, practically no load being transferred to the soil between the piles.

Paper 8.06.b

"Failure of Two High Embankments at Soft Soil Site"

by D. Roy and R. Singh (INDIA)

The paper discussed the failures of two highway bridge approaches constructed of mechanically stabilized earth near Calcutta, India. The bridge approaches were founded on soft, compressible fine grained soils of the intertidal flats and backswamps of the Ganges Delta, with the embankments retained by mechanical stabilized earth (MSE) walls constructed of compacted rivers sand reinforced with galvanized steel. Deep seated circular failure surfaces through the soft foundation soils occurred in both cases during or immediately after construction. The post-failure analyses indicated the cause of the failures was inadequate assessment of the subsurface conditions, the MSE walls failing due to global stability without significant internal distress.

The strength parameters for the original design were based on the assumption that the average degree of consolidation will reach 90% under the surcharge of the embankment. In reality, due to rapid construction rate this consolidation was not achieved. Investigation after embankment failure consisted of Standard Penetration Tests (SPT), collection of undisturbed samples, and field vane tests. Unconsolidated–undrained (UU) triaxial compression tests on undisturbed samples, moisture content, grain size distribution, and Atterberg Limits performed on collected disturbed samples indicated the foundation consisting of a layer of soft silty clay of Holocene age containing organic materials overlaying a layer of stiff silty clay of Pleistocene age. The ground water encountered during investigation varied between 1.0 and 1.5 meter below the surface. Results of limit equilibrium stability analyses indicate the structures were marginally stable at the time of failure. Similar MSE embankments in these areas constructed on stabilized foundation soils by installation of a drainage system (PVD – Colbonddrain@CX1000 15 ft deep at 1.5 m centers square grid) followed by pre-loading of the foundation were stable since the construction was completed. Remediation measures consisted of consolidation of the foundation soils with PVD, than construction of a stabilizing berm to a certain height and construction of the MSE wall on the top of this berm providing conditions for consolidation of the soil.

Fig.1, Paper 8.06.b: Failures at KM 26 and KM 18 site.

Paper 8.08.b

"Damage to Road & Sports Complex on Expansive Clays"

by M.B. Mgangira and P. Paige-Green (SOUTH AFRICA)

The paper discusses damages to a road pavement in Ethiopia and to the roads and structures of a large sport complex in Botswana founded on typical African black cotton soils known for their expansive characteristics due to changes in volume with fluctuation of the moisture content. The distress of the road in Ethiopia consisted of longitudinal cracking of the shoulders and of the asphalt in the outer portion of the roadway blamed on the foundation soils. To prevent further damages new sections of the road were constructed on improved foundation material by replacing the black cotton soil layer in the foundation of either side of the roadway with imported material leaving the middle portion of the road untouched. These new sections developed similar distress. Further investigation indicated the foundation soil was potentially active, with high variations in the moisture conducting to high changes in volume.

The investigation indicated that inappropriate materials were used for construction besides the fact that no improvement of the foundation soil was considered. Field Disturbed samples were collected from test trenches. The samples were tested in laboratory to determine moisture besides other testing such as Atterberg Limits and particle size distribution. The investigation indicated the road foundation consisted of African black cotton soil with high content of montmorillonite, with some kaolinite and halloysite. The foundation soils were characterized as high to very high degree of expansiveness due to high variation of the moisture content (between 24 and 53%) and medium to high potential swell. The Atterberg limits indicate the foundation soil consisted of high plasticity clay soils (with the Liquid Limit LL and Plasticity Index PI varying between 43 and 103, and 9 and 54 respectively). Estimation of the expected heave along the investigated road sections show values ranging between 24 mm and 70 mm. The fill materials in the road shoulders consisted of volcanic ash and tuffaceous material, replaced by red silty clay in sections where partial replacement technique was used. The fill materials were also high plasticity soils with LL higher than 50 with high swelling potential. The materials used were not adequately inert and no measures were taken to minimize the movements within themselves, conducting to additional heave. The drainage control along the road was also inadequate, ponding water at the toe of the road being observed in some areas.

The sports complex in Botswana was constructed on fill rom surrounding weathered Mesozoic basalt. The stadium structures and the athletic track were constructed on piles and show no distress. All the other structures of the complex show distress of various form of degree. Some improvements on other structures were to place the structures on soil rafts, to provide vertical vapor barrier in the form of the plastic sheeting at the edge of the rafts, to provide flexible joints for wet services, to construct concrete aprons around the buildings, to construct reinforced concrete ground beams and ring beams above windows and to control the storm water on the site. However, generally single storey structures were not articulated for differential movements. All these measures reduced the extent of the damages without to prevent them. Earlier investigation show expansive clays in the foundation soil to a depth between 6 and 8 m. Undisturbed and disturbed soil samples were collected from test pits up to 3 m deep. Laboratory tests on these samples show the moisture content varying between 10.8 and 32.9%. Oedometer tests show heave predictions varying between 0.2 and 6.7% and swell prediction between 4.6 and 6.7%. The tests on the fill material show that the fill material having a PI of 13% does not compliant with the necessary requirements. In conclusion the investigation show the fill material was not adequate and the remediation measures were not properly designed, i.e., the rafts were not sufficient extended beyond the footprint of the buildings.

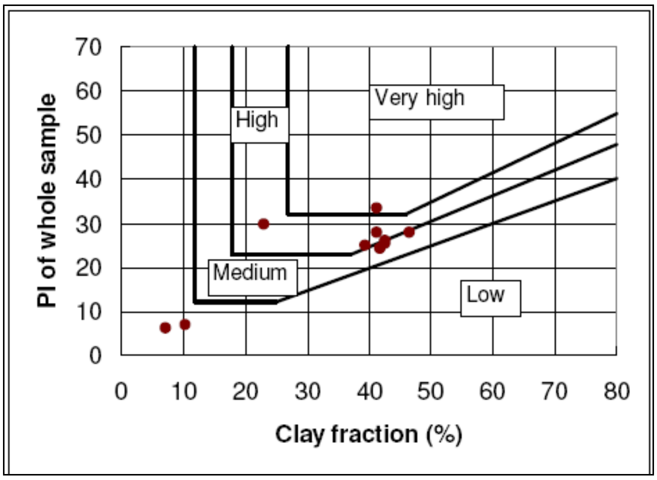

Fig. 17, Paper 8.08.b: Plots of predicted heave using modified van der Merwe chart.

Paper 8.13.b

"Forensic on Construction Induced Failure of Pipe Pile Foundations"

by X. (Bill) Yu (USA) and Y. Huang (CHINA)

The paper analyzed a case of pipe piles failure during construction of a pumping station in southern China. The pumping station is part of a comprehensive hydraulic project for JiaoMen Canal. Pre-stressed concrete piles were used to reduce the settlement of a thick soft soil layer in the foundation of the pumping plant house. Prior pile installation the foundation soil was treated by cement deep mixing. The deep mixing cement columns diameter was 0.5 m at distances from 1.10 to 1.15 m. The piles were installed to a depth around 35 m below the ground. Severe inclinations of the piles were observed during the excavation for the grading of the area. Results of post-accident survey indicated that the maximum lateral displacement at the top of the piles reached 2.6m. Forensic investigation immediately after the accident determined that the disturbance of the thick soft layer was the major cause of the pile failure. The soft layer consisted of a very loose sludge (low penetration resistance) with high water content. The tip of the piles was placed in a lower fine sand layer. Due to the vibration during the pile installation the sludge layer behave like a liquid, flowing gradually during the excavation, applying an unbalanced lateral force on the piles and offering insignificant amount of lateral resistance. The unbalanced lateral forces associated with the lack of lateral support of the piles caused large bedding moment action on the piles causing the failure of the spices. Pile integrity tests and inclinometer measurements were included in the forensic investigation. The paper analyses the pile breakage mechanism, estimating the drag forces generated by the flow of the soft sludge around the piles based on turbulence induced vibration. Based on the forensic study the authors provided recommendation for pile construction such as placing pad under construction to reduce vibration, field monitoring program, avoidance of steep slopes during construction.

(a)

(b)

Fig. 2, Paper 8.13.b: Severe inclination observed during excavation a) construction; b) pipe pile inclination.

Paper 8.01.c

"An Evaluation of the Geotechnical Characteristics of the Abutments of a Proposed Bridge across a 400-meter River Channel in the Lower Niger Delta, Nigeria"

by S.C. Teme and E. Ubon (NIGERIA)

The paper provides information on the geotechnical characteristics of the foundation soils of the abutment of a 400 m long bridge across the Niger Delta. The Niger Delta is zoned into three zones. The sub-soils of the "Coastal" or Lower Delta Zone consists consist of sand, silts and highly plastic clays in some inlet areas, the sub soils in the 'Transition' Or Mangrove (Middle Delta) Zone are characterized by a typical fibrous, pervious clayey mud (that exhibits large values of compressibility and consolidation), underlain by silty sands which most often grade into poorly-graded sands and further downwards into well-graded sands and gravels and in the "Freshwater" or Upper Delta Zone consists of a lateritic clay layer usually underlain by silty clays and silty sands which are further underlain by poorly-graded sands and sands and gravels. The rainfall in the area ranges between 200 Freshwater Zone to 4000 in the Coastal Zone. The bridge presented in the paper is located within the Tropical Zone.

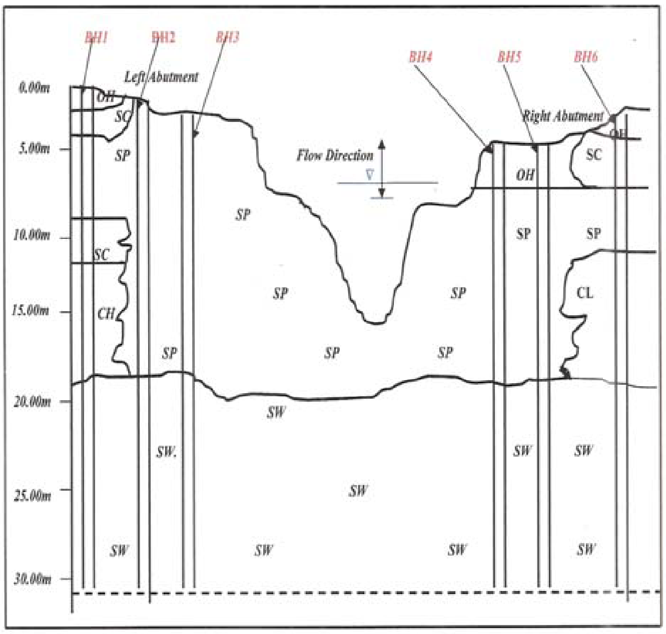

Fig. 5, Paper 8.01.c: Subsurface stratigraphy across the bridge abutments at the New Calabar River.

The project's subsurface investigation included Standard Penetration Tests (SPT) with the aid of Shell-Percussion Rig, Cone Penetration tests (CPT), and laboratory testing. Laboratory testing consisted of visual classifications, grain size analyses, Atterberg Limits, Determination of unit weights, unconsolidated undrained triaxial compression tests, and consolidation tests. Based on the subsurface investigation and the bearing capacity, deep foundation using steel hollow cylindrical pile foundation was recommended. The paper summarizes results of the laboratory tests and provides design information such as depth of piles, piles cross sections, ultimate carrying pile capacity for both bridge and abutment piles. The piles will be anchored in the well graded sands and gravels at depths from 20 and 25 m, expecting minimal settlement.

Paper 8.02.c

"**Subsurface Geotechnical Engineering Investigations for a 9.833-Km Long Road and 130-meter Wide Bridge in a Karst Topography In South-South Nigeria"**

by S.C. Teme and E. Ubong (NIGERIA)

The paper presented the foundation conditions and design of a bridge crossing the Kwa River located in the Tropical Zone of the low-lying Eastern Calabar Flanks in the south-eastern section of the Niger Delta sub-region of Nigeria that extends from the Imo River to the Cross River estuary at the Nigerian-Cameroon border. The coastline is characterized by flat sand beaches behind which are mangrove swamps. The sub-soils in the area consist of Organic Silty Clays (OL), Well-graded

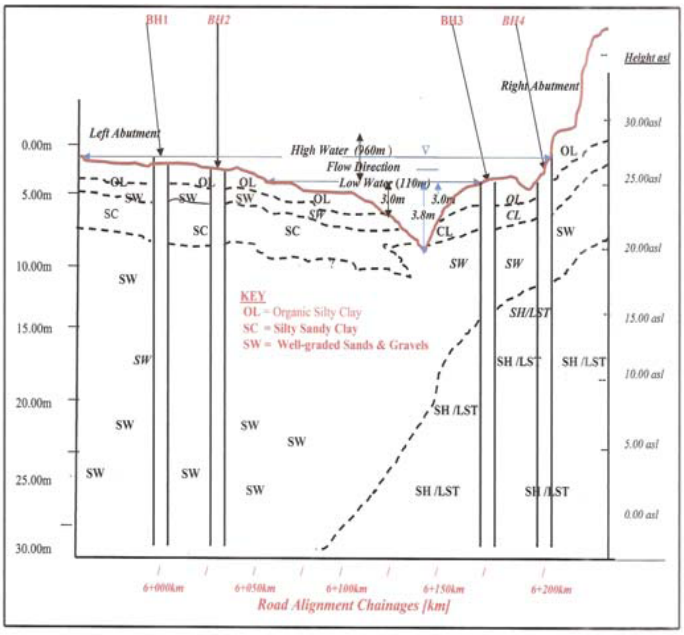

Fig. 5, Paper 8.02.c: Subsurface stratigraphy across the bridge abutments at the Kwa River.

Sands and Gravels (SW) and Sandy Silty Clays (SC) at the left abutment of the proposed bridge across the Kwa River, while 1 m of greyish Sandy Silty Clays (SC) and 5 m of organic Silty Clays (OL) form materials at the right abutment of the same bridge. These materials are all underlain by indurated Shale and Limestone to depths beyond 30 m at both abutments of the bridge. The climate of the zone is basically that of tropical monsoon with rainfall of over 4000 mm, occurring almost all through the year except the months of December, January and February.

The paper describes the vegetation of the area consisting of red and white mangrove and palm trees. The subsurface conditions were determined based on the Standard Penetration Tests (SPT) and laboratory testing on samples collected by the drilling program including visual classifications, grain size distribution, Atterberg Limits, unit weights, unconsolidated–undrained triaxial compression tests and consolidation tests. Deep foundations using reinforced steel hollow cylindrical piles were recommended, considering the foundation condition and the bearing capacity determined. The paper provides some design analyses such as design of the pile depth and piles cross section considering the base resistance and skin friction of piles, ultimate carrying capacity of the piles, and settlement.

Paper 8.04.c

"**Design, Behavior of Salgueiros Station for Porto Metro"**

by A.T. Gomes, A.S. Cardoso, J.A. e Sousa (PORTUGAL) & J.C. Andrade, C.A. Campanhã (BRAZIL)

The paper presents the design and construction of an elliptical 22 m deep excavation of the Salgueiros Station for Porto Light Rail Metro. The large, free open surface space permitted an unusually solution for the excavation, containing the rectangular the shape of the excavation within two ellipses, and taking full advantage of this new shape, by mobilizing the arch effect on the ground. The excavation was performed using the Sequential Excavation Method and the support materialized by a shotcrete membrane whose thickness varied from 0.3 m, in the upper part, to 0.6 m at the base of the excavation. The geotechnical characterization of the sub-soils was based on intensive in situ and laboratory testing of the typical granite residual soils that covers that large area of the northern part of Portugal, being the material predominant at most superficial horizons in the city of Porto, where the excavation here presented was performed. These soils are saprolitic materials, preserving the natural fabric of the original rock, with less than 10% clay, around 20% silt and almost 70% sand. Most superficial materials have a weathering degree where the structure of the material completely disappeared. As the weathering degree decreases, the massif maintains the fabric of the original rock but with strength and deformability typical of soils. The granite mass has sudden changes in its weathering degree, being completely erratic the changes both in vertical and horizontal directions. The results of the field tests and laboratory tests which conducted to the selected design parameters are presented. In addition, the paper presented the numerical model using finite element method and additional calculations used for the design of the excavation. The paper provides details of the construction technique, construction sequences, drainage and dewatering during construction. An analysis of the excavation behavior during and after construction included the monitoring plan containing installation of piezometers for surveying the ground water elevation during construction and installation of crackmeters and inclinometers to determine real displacements. Settlements and displacements were closely monitored during and after construction at the site excavation site and outside at different distances were compared with results of the design analyses.

Fig. 5, Paper 8.04.c: Final excavation phase.

The conclusion of the paper is that simplified numerical model predicted satisfactorily the behavior of the excavation. However, detailed analysis of the monitoring results evidenced certain differences between what was expected in the design and the real behavior of the works, differences that were basically concentrated in the magnitude of the movements and in the forces in the transversal beam, a vital element in the overall stability of the structure. A 3D numerical modeling of the excavation, taking into consideration the non saturated behavior of the soil could clarify some aspects of the problem.

Paper 8.05.c

"**Bond Strength of Hollow-Core Bar Micropiles"**

by J.E. Gómez, C.J. Rodriguez, H.D. Robinson, J. Mikitka, and L. Keough (USA)

This well documented paper presents the retrofitted foundation of two bridges using hollow core bar micropiles. The micropiles for one of the two bridges were installed in submerged granular soil, and for the second bridge in predominant fine soils. The micropiles were drilled using a lean cement grout which was re-circulated for de-sanding and re-use. Final grout was injected upon completion of drilling to the design tip elevation. The micropiles were designed for an allowable capacity of 80 kips. The foundation of the two bridges contains unconsolidated sediments consisting of layers of sand, silt and clay deposited alternately in deltaic and marine environments as sea level fluctuated during cretaceous and Tertiary times. The very soft organic silt in the foundation extends to a depth between 3 m at one bridge and 4.3 m at the second bridge, overlying a approximately 14.7 m thick medium-dense sand or a stiff to very stiff silt respectively.

Fig. 3, Paper 8.05.c: Installation of production micropiles with limited headroom.

Fig. 4, Paper 8.05.c: Drilling hollow core bar test micropile.

The paper presents the procedure for installation of the micropiles, including drilling methods under limited headroom and within temporary cofferdams, casing installation, insertion of the hollow core bar, and grouting procedures. Grouting mix design, grout pressures, drilling rates and grout testing were also provided. The paper included the quality control of the micropiles, the results of the verification and proof load tests performed for this project. The interpretation of the test data, measurement of the ultimate bond values in sand and stiff clay, and comparison to published data show that the bond strength estimated for the hollow core bars in the granular soils are larger than those values suggested by the design guidelines used for the design may be due to the beneficial effect of partial mixing of soil and grout in the periphery of the grout body, and to the penetration of the grout into the soil mass outside the micropile. The bond strength values estimated for micropiles installed in the fine-grained soils are within the range of values proposed by the same guidelines.

<u>Paper 8.08.c</u>

"**Ancient Landslide Reactivation at Viaduct No. 1 Located on Caraca-La Guaira Highway, Venezuela**"

by L.B. Fargier-Gabaldon, D.A. Salcedo, & R. Camargo-Mora (VENEZUELA)

The paper summarizes results of the geotechnical investigation, the evaluation of inclinometer readings and surface control points of a reactivated old that affected the southern side of a big viaduct located in the Caraca-La Guaira Highway, connecting the capital of Venezuela, Caracas, with its main seaport and the Simon Bolivar International Airport. Three bridges (Viaduct Nos. 1, 2, and 3) and two large tunnels are some of the major structures of the highway. Viaduct No. 1 consists of 3 paralleled double hinged arch ribs designed to resist compression stresses covered a central span of 152 m. The paper provided information on the structure and foundation of the Viaduct No. 1.

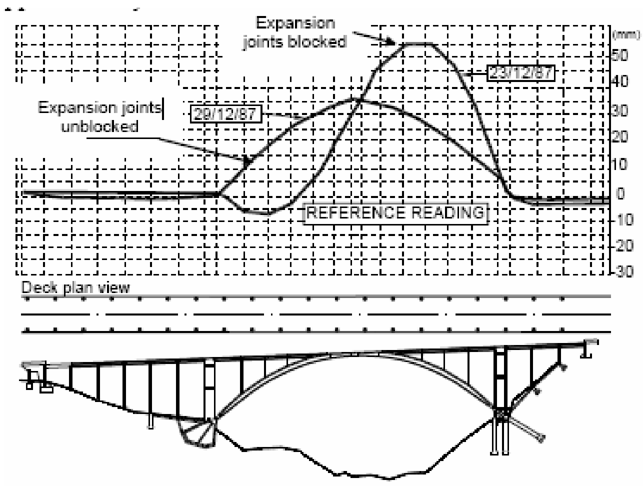

Fig. 11, Paper 8.08.c: Deformation profile of the deck in 1987.

Following a landslide occurring in 1987 that affected the expansion joint at the Caracas Abutment the area was intensively investigated, including geomorphologic studies and exploratory borings. The geomorphologic investigation showed an ancient landslide at the Caracas side of the viaduct.

Due to construction of numerous houses within the unstable area which lacked of sewage disposal and drainage facilities, the sewage system was drained into the ground. A fault running parallel to the alignment of the first kilometers of the Highway close to Caracas is part of the Tacagua-Avila fault system which is geological active and is responsible for recent small earthquakes in Venezuela.

Exploratory borings show the lower hill under the highway mainly covered by a colluvial material derived from the ancient landslide. The area is monitored by a surface displacement system and piezometers, inclinometers and extensometers. The paper describes the landslide mechanism and the emergency work provided until March 2006 when the viaduct finally collapsed. Details on design analyses, damages occurred, field observation and measurements and comparison with design analyses, rehabilitation measures and repair work are included in the paper. One conclusion is that the initial landslide in 1967 could have been triggered by the Caracas earthquake.

Paper 8.09.c

"Damage of Railway Sleepers under Dynamic Loads: a Case History from the Greek Railway Network"

by K. Giannakos (GREECE)

The paper analyses the causes of cracks presented on 60% of the twin-block concrete ties laid on a track with maximum operational speed of 140 km/h. The concrete ties were designed for a speed of 200 km/h. A model is developed to determine the load on the track's superstructure considering the geotechnical conditions at the track. Details on the acceptance criteria of the strength of the concrete ties, for pre-cracking, post-cracking, and post-serviceability cracking stages are provided. Static loads due to the wheel load and due to cant deficiency are calculated. Dynamic loads caused by the suspended and non-suspended masses calculated according to German and French bibliography, and using formulas derived from the conditions of the Greek network are compared. The paper provides details of the numerical simulations on a twin-block tie and mono-block ties of the Greek network including the use of high resilience fastening. An application for the heavy haul rail transport in case of a track equipped with fastening and concrete slippers is provided.

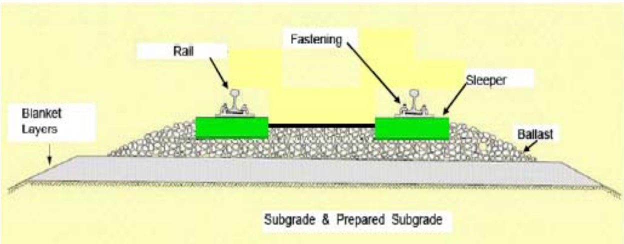

Fig. 1, Paper 8.09.c: Typical section of ballasted track with twin-block concrete ties.

Paper 8.12.c

"Case Histories Back Analyses for Application of the Eurocodes Observational Method for the SCOUT Project"

by H-C Yeow and I. Feltham (UNITED KINGDOM)

The paper describes briefly the project background, design optimizations and back analyses undertaken of retaining wall case histories to develop a methodology to derive design parameters appropriate for the implementation of the Observation Method under the framework of Eurocodes. The European Commission (EC) funding Sustainable Construction of Underground Infrastructure (SCOUT) project introduced a breakthrough for the construction of "cut-and-cover" tunnel using a horizontal diaphragm walling equipment with the implementation of the Observational Method for the construction of the underground structure. Design optimization options such as the use of different structural forms, new construction material and even design approaches were explored in an attempt to provide a sustainable design for the underground structure.

Project name	Excavation depth, H (m)	Max measured deflection, δ (mm)	δ/H (%)	E_u/c_u ratio
Project Lateral	12	10	0.08	1250
Kings Place	16	29-40	0.2-0.25	900-1200
KX Hub Shaft	21.3	11-13	0.05-0.06	1250
Thames Link Box	11	5	0.045	1500*
Ropemaker	6-7	6-12	0.1-0.2	1000-1600

From Paper 8.12.c: Summary of Case Histories back analyses.

One of the EC considerations is that the design should verify that no relevant limit state is exceeded, as limit state being considered the ultimate and serviceable limit states. Partial factors applied to the actions or effect of actions, and to the soil parameters or the resistance are dependent on the three design approaches described in detail in the paper. The retaining wall design optimization goal was to achieve sustainable construction through more efficient design hence more effective use of construction resources. The paper describes different aspects of the design optimization based on the qualitative assessment including the analytical model used, crack width consideration particularly in respect to their influence in cost, water ingress and corrosion of both bar and steel fiber reinforcement, benefits and disadvantages of including non-metallic fibers, water-stops, crack-inducers and drains, and structural form which allows bending moment continuity between walls and slabs, provision of haunches to aid arch action in slabs, beneficial effects of axial load in the slabs and horizontal bending moment continuity. Regarding the design parameters used in the optimization method (OM) design approach differs from a conventional design where most probable and characteristic geotechnical design parameters are used to establish the range of behavior of the structure by allowing the use of stringent construction control to tap into the potential benefits between most probable and characteristic designs. The OM approach is entirely different to the conventional design approach, which relies on a generally conservative design with monitoring, if at all carried out, playing a very much passive role to check original predictions are still valid. In OM the monitoring of instruments plays an active role in both design and construction, allowing planned modifications to be carried out within an agreed contractual. Back analysis of five case histories approach was used to derive the most probable geotechnical parameters for the design using the OM approach. Rigorous sensitivity analyses were performed to identify the governing parameters for retaining structure, which is essential in the design framework under the Eurocode. Design optimization assessments undertaken in the cut-and-cover retaining structure analyses have shown substantial savings in materials and overall cost.

Paper 8.13.c

"**Investigation on the Causes of Longitudinal Cracks on Prestressed Monoblock Railway Sleepers of Metric Gauge of the Greek Railway Network"**

by S. Tsoukantas, K. Tzanakakis, D. Spyropoulou, and P. Panopoulos (GREECE)

Fig. 6, Paper 8.13.c: Cracked sleepers.

The authors described and analyzed the longitudinal cracks observed in some of the pre-stressed monoblock sleepers of metric gauge during the rehabilitation of the Greek Railway Organization (OSE) line Korinth – Tripolis – Kalamata. The paper provided information on the methodology adopted by the committee that investigated the causes of the distress, e.g. on site investigation of the damaged sleepers, investigation of the probable causes of the cracks during the production of the sleepers (faulty concrete grade – faulty pre-stress level and other), with theoretical considerations which, all together, led to the cracking of the sleepers. Theoretical consideration included estimation of the degree of prestress in the rail seat, qualitative aspects of stress conditions in the interface concrete-sleeper screw under tightening torque, and finite element analysis to estimate multi-axial stress conditions in the concrete area around the sleeper screws, due to simultaneous action of the prestress force and the screw actions.

The authors concluded that the sleepers cracked longitudinally due to the high level of the tightening torque that was applied to the sleeper screws. It seems that high values of the tightening torque, depending also on the age of the concrete, may provoke sliding of the screws which together with the existing pre-stress stresses lead to the cracking of the sleepers.

TOPICS FOR DISCUSSION

Items for discussion stemming from Session 8:

– Innovative methods for support of excavation in the unique geologic environment of Washington, DC area.
– Design phase testing to optimize large foundations.
– Methods the Geotechnical Engineer can apply to contribute to sustainable design.
– Geotechnical probabilistic risk assessment and its value in large public projects.
– Setting priorities and specifications for field and laboratory testing in under- or un-developed countries.
– MSE walls applications in difficult soil conditions.
– Properties and design considerations for expansive clays.
– Vibration effects on piles due to installation methods.
– Lessons learned from monitoring of deep excavations and back analysis with numerical tools.
– Bond strength evaluation for micropiles design.
– Value of historical reviews and observations of old failure in predicting future behavior of geotechnical structures.
– Analysis of railways under dynamic loading.
– Sustainable Construction of Underground Infrastructure program's Observation Method by European Commission.

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